The Terrestrial Carbon Cycle and the EC-ESA Earth System Science Initiative

Agora

Wednesday 25th May 2022

esa
living planet symposium BONN 23–27 May 2022

Recommendations for Action from the 3rd Carbon from Space Meeting (Land)
Progress in the last 5 years

The following series of recommendations were made during the 3rd Carbon from Space meeting in 2016. At the Living Planet Symposium we have organised an Agora discussion session to review progress against these recommendations and look ahead to the 4th Carbon from Space meeting.

We would be very grateful for any observations on what has been done over the last 5 years and what is still to be done, what new issues have arisen.

1. Budgets – Regional

Number	Description	Progress made	What needs to be done
1	Improve partitioning between land and ocean at the regional scale		
2	Reduce discrepancies between methods to estimate regional carbon sinks and uncertainties in models at the regional level.		
3	Improve understanding of actual drivers of sinks at both global and regional levels;		
4	Reduce uncertainty in emissions (both fossil and LUC) and generate annual estimates of LUC to account for important processes (e.g., ENSO-related variability);		
5	Improve understanding of and characterise the CO_2 effect versus the effect of climate (and land-use).		
6	Explicitly include transport of carbon from land to the oceans		
7	Address inconsistency within inversions for both natural CO_2 and CH_4 fluxes		
8	Investigate regional differences between satellite and in-situ observation inversions for natural CO_2 fluxes.		
9	Estimates of the global terrestrial carbon sink need to be explicitly derived rather than being based on the residual derived from the difference of the other components		
10	For long-term (decadal) carbon balance, improve information on disturbance and regrowth, for an assessment of the site history: Biomass and biomass change; High resolution atmospheric CO_2 concentrations Fluorescence Soil moisture Diurnal cycles		

9 Recommendation groups	Number
Budgets – Regional	10
Fluxes – Regional	3
Fluxes - Land-atmosphere	5
Attribution	4
Extremes	2
Tipping Point/Sensitive Regions	10
Fossil Fuel CO2	5
Address key areas	4
Improve coordination	1

The 3rd CfS recommendations will be placed online after LPS. If you wish to contribute please let us know

10	For long-term (decadal) carbon balance, improve information on disturbance and regrowth, for an assessment of the site history: Biomass and biomass change; High resolution atmospheric CO_2 concentrations Fluorescence Soil moisture Diurnal cycles
14	Need further development and testing of data assimilation systems with multiple data streams in parallel with forward model developments e.g. TRENDY project and model-independent data-driven machine learning approaches.
42	Key areas: Carbon dynamics in the boreal permafrost region

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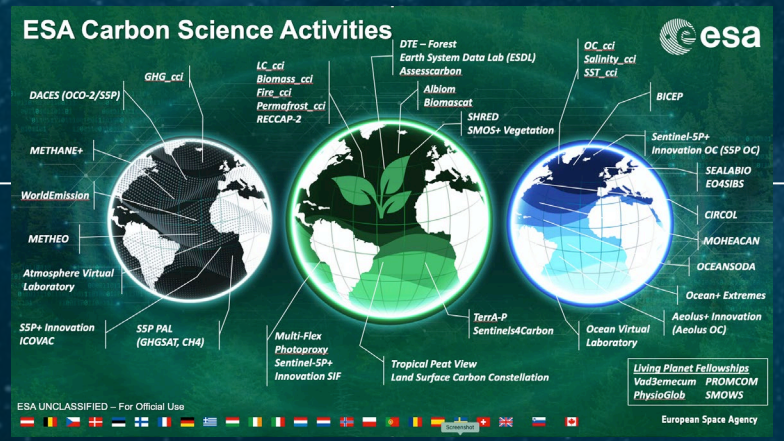
Num	Recommendation	Progress made	What needs to be done
44	To coordinate between existing structures e.g. NASA CMS, WMO IG3IS, and research efforts of GCP e.g. RECCAP, UCRM and infrastructural networks such as ICOS, NEON and TERN	• Improved in situ/satellite contacts • Improved coordination across projects e.g. ESA Carbon Science Cluster • Improved coordination across agencies e.g. AMPAC, EC-ESA ESSI • Improved use of satellite data in e.g. RECCAP-2 • Support for RECCAP-2	



Terrestrial Carbon Constellation

A new era in terrestrial carbon observations from space

In few years from now, ESA will launch FLEX and BIOMASS complementing a large set of complementary missions such as the Sentinels 1, 2, 3 and 5P, SMOS and novel missions from partner space agencies… EnMAP, PRISMA, NISAR, GEDI…

This "constellation" will offer an unprecedented opportunity to enhance our capacity to assess and quantify the terrestrial carbon cycle and its dynamics from space…

ESA is preparing for this challenge (a few activities have already started) and a new large initiative is in preparation to be launched in 2023 in partnership with the EC. To help prepare for this, feedback from the community is critical:

- **What are the main opportunities and challenges?**
- **What are the main priorities to be addressed?**
- **What can be a realistic output for 2025 (next LPS)?**

A new large initiative is in preparationon terrestrial carbon to be launched in 2023 in partnership between ESA and EC. To help prepare for this, feedback from the community is critical:

- What are the main opportunities and challenges?
- What are the main priorities to be addressed?
- What can be a realistic output for 2025 (next LPS)?

Agenda

17:25 – 17:35	Introduction to Agora	Stephen Plummer
17:35 – 17:45	The Earth System Science Initiative	Gilles Ollier/Diego Fernandez
17:45 – 18:05	Progress since 2016 and Key Gaps – Views from the Community	
	• Marko Scholze (Lund, SE)	
	• Ana Bastos (MPI-BGC, DE)	
	• Jose Moreno (UV, ES)	
	• Fabienne Maignan (LSCE, FR)	
18:05 – 18:20	Open discussion	
18:20 – 18:25	Next Steps	Stephen Plummer

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4th Carbon from Space

25–28 October 2022 | full hybrid event

…brings together the EO, in situ and Earth system science communities to identify gaps, challenges and issues to address in understanding the terrestrial component of the carbon cycle and its interactions with the ocean and atmosphere.

	Day 1	Day 2	Day 3	Day 4
9:30-11:00	**Session 1** Introduction and Scene Setting	**Session 3** Land use change and agriculture impacts on the carbon cycle	**Session 5** Forests and the Glasgow Leaders' Declaration – can we monitor its impact?	**Session 8** Global-regional-national assessments for the global stocktake
11:30-13:00	**Session 2** Opportunities with new data	**Session 4** Model-Data interfaces – what are the gaps and opportunities	**Session 6** Extremes, multi-hazards, disturbance and vegetation response	**Session 9** Recommendations/Next Steps
14-15:30	Community Sessions	Community Sessions	Community Sessions	
17-19:00	**Session 2** Opportunities with new data	**Session 4** Model-Data interfaces – what are the gaps and opportunities	**Session 7** Carbon in the Arctic	**Session 9** Recommendations/Next Steps
19:15-21:15	Community Sessions	Community Sessions	Community Sessions	

Objectives

1. To review progress against the recommendations of the 3rd Workshop
2. Establish a revised strategic plan of research and development activities to guide the programmatic actions and investments and related application development on terrestrial carbon research for the time frame 2023–2028.

http://4thcarbonfromspace.esa.int

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Num	Recommendation	Progress made	What needs to be done
14	Need further development and testing of data assimilation systems with multiple data streams in parallel with forward model developments e.g. TRENDY project and model-independent data-driven machine learning approaches.	• Improved model benchmarking (ESMVal, iLAMB etc) with satellite records • ML methods e.g. FluxCOM for comparison • Progress on data assimilation and model improvements e.g. land Carbon Constellation Study	• Need to improve satellite product consistency and product use • Improve interfaces between model and data – do they observe the same things? • Move toward RT based Observation operators? • Move to [use of] higher resolutions in models

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Earth System Science Data

Comparing national greenhouse gas budgets reported in UNFCCC inventories against atmospheric inversions

Zhu Deng[1,★], Philippe Ciais[2,★], Zitely A. Tzompa-Sosa[2], Marielle Saunois[2], Chunjing Qiu[2], Chang Tan[1], Taochun Sun[1], Piyu Ke[1], Yanan Cui[3], Katsumasa Tanaka[2,4], Xin Lin[2], Rona L. Thompson[5], Hanqin Tian[6], Yuanzhi Yao[6], Yuanyuan Huang[7], Ronny Lauerwald[8], Atul K. Jain[9], Xiaoming Xu[9], Ana Bastos[10], Stephen Sitch[11], Paul I. Palmer[12,13], Thomas Lauvaux[2], Alexandre d'Aspremont[14,15], Clément Giron[14], Antoine Benoit[14], Benjamin Poulter[16], Jinfeng Chang[17], Ana Maria Roxana Petrescu[18], Steven J. Davis[19], Zhu Liu[1], Giacomo Grassi[20], Clément Albergel[21], Francesco N. Tubiello[22], Lucia Perugini[23], Wouter Peters[24,25], and Frédéric Chevallier[2]

[1]Department of Earth System Science, Ministry of Education Key Laboratory for Earth System Modeling, Institute for Global Change Studies, Tsinghua University, Beijing 100084, China
[2]Laboratoire des Sciences du Climat et de l'Environnement, IPSL, CEA-CNRS-UVSQ, Université Paris-Saclay, 91190 Gif-sur-Yvette, France
[3]Jiangsu Provincial Key Laboratory of Geographic Information Science and Technology, International Institute for Earth System Science, Nanjing University, Nanjing 210023, China
[4]Earth System Risk Analysis Section, Earth System Division, National Institute for Environmental Studies (NIES), Tsukuba, Japan
[5]Norwegian Institute for Air Research (NILU), Kjeller, Norway
[6]International Center for Climate and Global Change Research, School of Forestry and Wildlife Sciences, Auburn University, Auburn, AL 36849, USA
[7]CSIRO Oceans and Atmosphere, Aspendale, Australia
[8]Université Paris-Saclay, INRAE, AgroParisTech, UMR ECOSYS, 78850 Thiverval-Grignon, France
[9]Department of Atmospheric Sciences, University of Illinois, Urbana, IL 61801, USA
[10]Department of Biogeochemical Integration, Max Planck Institute for Biogeochemistry, Hans Knöll Str. 10, Jena, Germany
[11]College of Life and Environmental Sciences, University of Exeter, Exeter, UK
[12]National Centre for Earth Observation, University of Edinburgh, Edinburgh, UK
[13]School of GeoSciences, University of Edinburgh, Edinburgh, UK
[14]Kayrros, 33 rue Lafayette, 75009 Paris, France
[15]CNRS & DI, Ecole Normale Supérieure, Paris, France
[16]NASA Goddard Space Flight Center, Biospheric Sciences Laboratory, Greenbelt, MD 20771, USA
[17]College of Environmental and Resource Sciences, Zhejiang University, 310058 Hangzhou, China
[18]Department of Earth Sciences, Vrije Universiteit Amsterdam, Amsterdam, the Netherlands
[19]Department of Earth System Science, University of California at Irvine, Irvine, CA 92697, USA
[20]Joint Research Centre, European Commission, Ispra (VA), Italy
[21]European Space Agency Climate Office, ECSAT, Harwell Campus, Didcot, Oxfordshire, UK
[22]Statistics Division, Food and Agriculture Organization of the United Nations, Via Terme di Caracalla, Rome, Italy
[23]Foundation Euro-Mediterranean Center on Climate Change (CMCC), Division on Climate Change Impacts on Agriculture, Forests and Ecosystem Services (IAFES), Viale Trieste, Viterbo, Italy
[24]Meteorology and Air Quality Department, Wageningen University & Research, Wageningen, the Netherlands
[25]Energy and Sustainability Research Institute Groningen, University of Groningen, Groningen, the Netherlands

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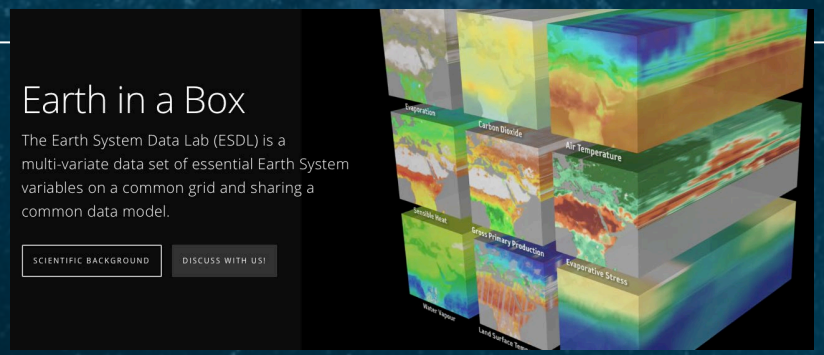

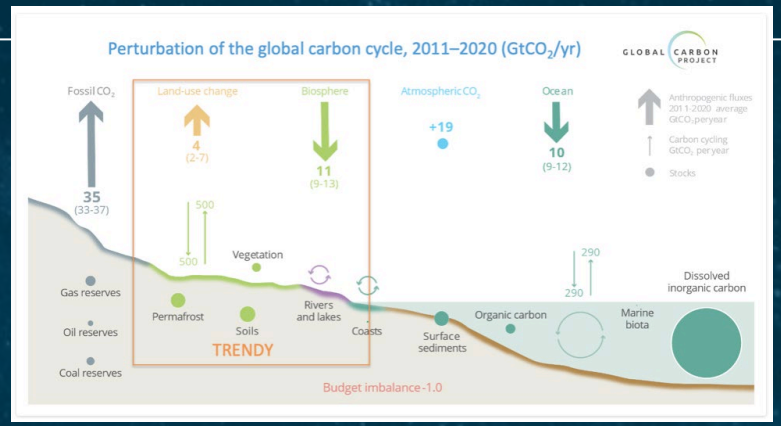

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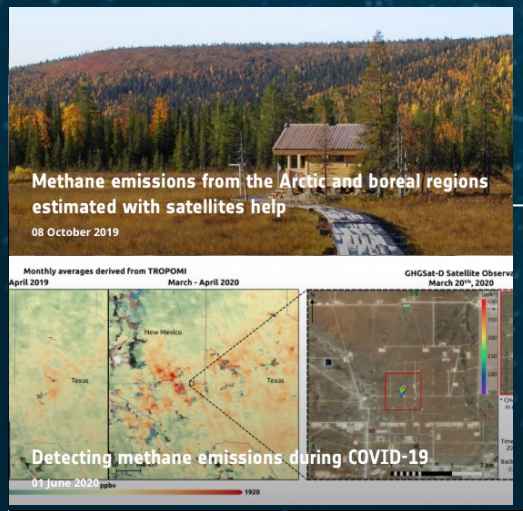

Num	Recommendation	Progress made	What needs to be done
12	There is a need to identify and quantify anthropogenic emissions consistently for policy-making and management, particularly given at least 70% of fossil-fuel CO_2 emissions are from urban areas.	• Efforts on in situ observation – ICOS Urban • Improved satellite CO2 observations – OCO-2, OCO-3, GOSAT, GOSAT-2 • Systems in planning e.g. CO2M • Satellite data use in atmos inversions • Top-down/bottom-up comparisons	• CO2 difficult to measure total column • Diurnal cycle limited sampling • Observations without sun (night, NH winter) • high resolution not yet for attribution especially urban/finite source
15	Need to quantify emissions from fossil fuels with spatial and temporal resolutions higher than those currently available.	• Number satellites increasing especially for methane with spatial resolution for super-emitter detection • New methods on e.g. S2	• increase resolution, sampling of diurnal cycle, longer term • calibrate all observations to community reference • combine measurements across satellites and with in situ

21	Improve understanding of changes in the global growth rate of methane, the locations of (changes in) sources, and the causes of these changes	• Better observations for anthropogenic especially super-emitters (and their correction)
		• New initiatives to understand processes e.g. AMPAC in permafrost
		• Global methane budget generated
			• Equivalent efforts to AMPAC on:
			  • Wetlands/peatlands in tropics, including rice paddies
			  • Coastal zone methane hydrates
			  • Fire and its dynamics
			• Global and regional effort to bring such efforts together needs support

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Num	Recommendation	Progress made	What needs to be done
26	Extend >30-m spatial resolution record and increase frequency from bimonthly to weekly	• Landsat 8 launched 2013 • Landsat 9 launched 2021 • Sentinel-2A launched 2015 • Sentinel-2B launched 2017 Work on combining different products ongoing between ESA and NASA Landsat-Sentinel-2 harmonisation (HLS, Sen2Like) Frequency of observation from 16 days to 5 days or better Improved services for processing (cloud) Continuity/improvement of SAR observations (Sentinel-1)	• Follow-on for Sentinel-2 planned Sentinel-2C (2024) followed by D and Sentinel-2NG. • Improved effort form regional-global processing • Consistency in processing with moderate systems • Combination with moderate systems • Combination with SAR • Consistency and complementarity of products generated
27	Add regional samples of high (< 1 - 10m) spatial resolution imagery	• A multitude of commercial systems - Planet, Worldview etc • National systems – Pleiades, Prisma etc • Daily observations global up to 3-5m	• Need to make these data more widely available for science and consistent calibration, geometry with public systems etc. • Processing capacity needed • Combination with public data for Earth System understanding

Num	Recommendation	Progress made	What needs to be done
1	Improve partitioning between land and ocean at the regional scale		
2	Reduce discrepancies between methods to estimate regional carbon sinks and uncertainties in models at the regional level.		
3	Improve understanding of actual drivers of sinks at both global and regional levels;		
4	Reduce uncertainty in emissions (both fossil and LUC) and generate annual estimates of LUC to account for important processes (e.g., ENSO-related variability);		
5	Improve understanding of and characterise the CO_2 effect versus the effect of climate (and land-use).		
6	Explicitly include transport of carbon from land to the oceans		
7	Address inconsistency within inversions for both natural CO_2 and CH_4 fluxes		
8	Investigate regional differences between satellite and in-situ observation inversions for natural CO_2 fluxes.		
9	Estimates of the global terrestrial carbon sink need to be explicitly derived rather than being based on the residual derived from the difference of the other components		
10	For long-term (decadal) carbon balance, improve information on disturbance and regrowth, for an assessment of the site history: Biomass and biomass change; High resolution atmospheric CO_2 concentrations Fluorescence Soil moisture Diurnal cycles		

Num	Recommendation	Progress made	What needs to be done
11	There remains a lack of consensus between top-down and bottom up estimates for the regional distribution of fluxes despite the inclusion of satellite data to complement for the sparseness of the ground observations		
12	There is a need to identify and quantify anthropogenic emissions consistently for policy-making and management, particularly given at least 70% of fossil-fuel CO2 emissions are from urban areas.		
13	There is an urgent need to develop advanced systems combining satellite and in-situ observations providing significantly more spatial information to resolve the sub-national and city scale		

Num	Recommendation	Progress made	What needs to be done
14	Need further development and testing of data assimilation systems with multiple data streams in parallel with forward model developments e.g. TRENDY project and model-independent data-driven machine learning approaches.		
15	Need to quantify emissions from fossil fuels with spatial and temporal resolutions higher than those currently available.		
16	Improve understanding of emissions of CH4 from wetlands and permafrost.		
17	Understand the effect of the nitrogen cycle on CO2 uptake and fertilisation or limitation processes.		
18	Include lateral fluxes (mainly transport through rivers) in process models since the anthropogenic disturbance may be as large as 1.0 Pg C yr-1		

Num	Recommendation	Progress made	What needs to be done
19	Need to improve the spatial resolution in attribution of natural sinks of CO2 from global/continental to regional or local level.		
20	Understand the causes of observed increases in the amplitude of the northern hemisphere seasonal cycle in CO2 and the role of terrestrial primary productivity		
21	Improve understanding of changes in the global growth rate of methane, the locations of (changes in) sources, and the causes of these changes		
22	Improve the spatial and temporal distribution of measurements for methane concentration and isotopes to understand and resolve the divergence between top-down and bottom-up estimates		

Num	Recommendation	Progress made	What needs to be done
23	Observational case studies show that the impacts of climate extremes can be identified via remote sensing. However, further studies are needed to understand spatial extent and duration of the impact on the carbon cycle.		
24	The interconnected processes through which climate alters the carbon balance are poorly understood and it is important to assess both the impact of extremes on the carbon cycle but also to fully understand the different processes involved.		

Num	Recommendation	Progress made	What needs to be done
25	Need for long-term, high precision observations in the atmosphere and at the ocean and land surface both in situ and from space		
26	Extend >30-m spatial resolution record and increase frequency from bimonthly to weekly		
27	Add regional samples of high (< 1 - 10m) spatial resolution imagery		
28	Augment 2-D data with (sub-metre) vegetation vertical structure		
29	Quantify photosynthetic rates and vegetation condition (global, sub-km)		
30	Improve spatial and temporal coverage and resolution (< 250 m) of coastal margins to constrain carbon/nutrient export from land to ocean		
31	Global measurements of CO2 and CH4 at 2-5 km^2 resolution, weekly		
32	Time resolved observations of CO2 over the diurnal cycle		
33	Other trace gas measurements for attribution (CO, NOx, DMS, H2S, OCS)		
34	International cooperation incorporating both broad swath, high resolution low earth orbit missions that cover the entire globe and geostationary missions to capture the full diurnal cycle and rapidly varying features		

Num	Recommendation	Progress made	What needs to be done
35	Increase in the density and spatial resolution of atmospheric CO_2 measurements from satellites, since fossil fuel emissions are concentrated over small areas.		
36	Before 2025, a high-resolution global imaging carbon mission to provide the capacity of quantifying fossil CO_2 emissions (≈3 km in size, precision of ≈ 1 ppm and systematic errors < 0.5 ppm.		
37	By 2030 a set of carbon missions for the frequent detection, quantification and monitoring of emissions including combined active and passive space-borne sensors and the close coordination internationally of space-based resources to provide continuity and resiliency to losses of data from individual satellites.		
38	Close coordination of space-based measurements with each other and with the surface in-situ monitoring network will provide greatest benefit if measurements are calibrated against internationally recognized standards		
39	The development of a Fossil Fuel Data Assimilation System (FFDAS) combining: Emission inventory information, Column integrated satellite CO2 measurements, combustion tracers related to fossil CO2 emissions (e.g., CO) and in-situ atmospheric measurements of CO2 and tracers (e.g., CO, 14C).		

Num	Recommendation	Progress made	What needs to be done
40	Wetland emissions		
41	Carbon in the tropics		
42	Carbon dynamics in the boreal permafrost region		
43	Carbon exchange of semi-arid regions		

Num	Recommendation	Progress made	What needs to be done
44	To coordinate between existing structures e.g. NASA CMS, WMO IG3IS, and research efforts of GCP e.g. RECCAP, UCRM and infrastructural networks such as ICOS, NEON and TERN		